NAL PROPOSAL No. 165

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PROPOSAL TO MEASURE TWO-BODY AND QUASI TWO-BODY ELASTIC SCATTERING AT LARGE t-VALUES AND IN THE μ-CHANNEL

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ABSTRACT

It is proposed to measure two-body and quasi two-body elastic scattering on p's, $\bar{p}$'s, $K^{\pm}$'s, $\pi^{\pm}$'s out to large t-values and at incident energies up to 150 GeV. In addition, it is proposed to measure the u-channel processes $\pi^{\pm}p \rightarrow \pi^{\pm}p$ at 40 and 75 GeV. Measurement will be made with the SASG focussing spectrometer.

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Introduction

The SASG group has proposed to measure the high energy diffractive scattering π's, K's, p's, and $\bar{p}$'s on hydrogen and deuterium out to $|t|$'s of $1.5(\mathrm{GeV}/c)^2$ using the high precision 200 GeV focussing spectrometer now under construction at NAL. This proposal was limited in its scope by time considerations and not by the inability of this instrument to make good measurements. (In fact an earlier proposal No. 73 by us which was later replaced by No. 96, did indeed envisage such measurements.) We are now proposing as a second round of measurements to go to large t-values. Other instruments at NAL will probably be able to do as well on the elastic channels, however the focussing spectrometer should have sufficient precision to measure elastic and quasi-elastic processes simultaneously, the mass of the recoiling nucleon or resonance being determined with high precision from the kinematics. In addition, the instrument will simultaneously accumulate data on incident p's, π's and K's. In our view this ability of a single arm instrument to make measurements simultaneously on a whole set of reactions makes this the preferred investigational technique for NAL.

The focussing spectrometer also has strong advantages for the u-channel investigations:

$$\pi^- + p \rightarrow p + \pi^-$$
$$\pi^+ + p \rightarrow p + \pi^+$$

The difficulty in identifying this second process $\pi^+ p \rightarrow p\, \pi^+$ is due to the fact that the cross section for either elastic pion or proton t-channel scattering into the spectrometer is larger by a factor $\sim 10^6$ over the u-channel.

At high input beam rates spurious events will sometimes be generated by protons in the input beam which t-channel scatter into the spectrometer and are simultaneously accompanied within the electronics gating time by a pion in the input beam. We propose to overcome these difficulties by taking advantage of the kinematic constraints that can be placed on these reactions with a high precision spectrometer. At 75 GeV incident energy the u-channel forward going proton is kinematically separated by ~1% in momentum from the elastically scattered t-channel particles. If measurements are made with a high precision spectrometer (capable of 0.1% or higher precision) the u and t-channel processes will be cleanly and completely separated on the basis of kinematics alone. In addition the presence in the parallel ray section of the focussing spectrometer of a high precision differential Cerenkov counter should provide almost complete particle identification and thus separate processes with a forward going pion from those with a forward going proton.

While beam intensities are very adequate for the t-channel processes, u-channel processes will be marginal unless relatively intense secondary beams are available.

Objectives of Proposed Experiments

While there are great numbers of predictions as to the high energy behavior of cross sections in the literature, it is clear that most are both speculative and model-dependent, and will be substantially modified as data becomes available.

In general at high t's and presently available energies, cross sections shrink rapidly with energy and thus appear to contain large or even predominant contributions from exchanges other than the pomeron. There is evidence that this shrinkage is decreasing with energy and that at NAL energies the cross sectional structure due to the pomeron, or pomeron cuts, should become dominant. Thus the NAL data should provide evidence on the high t behavior of the pomeron. Further in analogy with Glauber theory one would perhaps expect a t-dependence showing a series of single, double, triple, etc. pomeron scatterings. It is clear that the qualitiative behavior, slopes, shrinkage, presence or absence of dips or structure, etc. will have to be known from experiment to make further progress in theoretical understanding of the dynamics of high energy processes. Comparisons of the large variety of pomeron exchange processes available at NAL will also be of considerable interest.

There are a number of specialized theoretical predictions which can be checked(1). For instance, it has been pointed out that a crude type of factorization appears to exist that leads to constant ratios between the cross sections for diffraction excitation of the various resonances.

A few years ago simple Regge poles were believed to account very successfully for baryon exchange processes. As more data became available on a wide range of interactions the theoretical situation has become much more obscure. At high energies the theory should contain only a few leading exchanges or cuts and the data should be considerably easier to understand on a fundamental basis. Probably the most interesting experimental range to cover is from $|u|$ values of $0\text{-}1.5(\mathrm{GeV}/c)^2$, covering the very pronounced dip structure in $\pi^+ p \rightarrow p\, \pi^+$ observed at $|u| = .15(\mathrm{GeV}/c)^2$.

Experimental

The equipment to be used and the spectrometer have been fully described in Proposal No. 96. No additional equipment will be required.

If the accelerator is at an intensity in the range $5\ 10^{11} - 5\ 10^{12}$ protons per pulse we will use the 2.5mr input beam in the mode for which momentum is recombined at the target, and will use the hodoscope systems in the input beam to determine the characteristics of the input beam. For accelerator beam in excess of 10^{13} protons per pulse hodoscoping the input beam line would become less appropriate and we would then use the 2.5mr beam in the "dispersed mode", combining the beam and spectrometer into an "energy loss" or "missing mass" focussing device. Basically all beam momenta in this mode are recombined to a single point at an achromatic focus at the momentum focal plane of the spectrometer. If a particle then loses energy in the target it will be displaced on the focal plane by a distance proportional to the energy loss. The advantage of this mode of operation is that even if the spread of momentum in the input beam is as high as 1.5(GeV/c) (1% slits at 150 GeV) the change in momentum in passing through the target can be determined to the precision of 45 MeV/c. The t-value to be measured will be selected by changing the input angle of the primary beam on the target. The prebend system envisaged for Experiment No. 96 makes accessible t-values up to about $5(\mathrm{GeV}/c)^2$. With slight modification higher t-values could be made available if this was desirable. Generally we will expect to take about a 1/2% momentum bite on the primary input beam.

Particle identification will be made with the Disc Cerenkov counters and threshold counters in the primary beam, and with differential and threshold counters in the spectrometer. We expect during the running of Experiment No. 96 to have mastered the technique of identifying pions, kaons, and protons in the input beam and simultaneously recording the missing mass spectra for all the input particle channels over an appropriate range in the spectrometer. Cross sections will be determined from the missing mass spectra via the standard method of analyzing the data into an elastic peak, Breit-Wigner resonances, and a smooth polynomial background. The proposed spectrometer resolution of 0.03% precision should be very adequate.

u-Channel Processes

The process $\pi^- p \rightarrow p \pi^-$ will be relatively simple to measure. The high momentum forward going positive protons will be trivially separated0from the large flux of negative beam particles scattering into the spectrometer. Therefore t-channel processes associated with negative input beam particles will not provide any serious backgrounds. We would expect with accelerator intensities of $3\ 10^{12}$ protons per pulse or greater to be able to make measurements up to the order of 75 GeV before running out of cross section. At 75 GeV beam momentum the momentum precision on the forward going proton, required to differentiate the two pion process $\pi p \rightarrow + 2\pi$ from the elastic process $\pi p \rightarrow p\pi$, is .04%, whereas the spectrometer should measure down to a precision of 0.03%. We therefore believe that sufficient kinematic precision will exist to separate the elastic peak. However in addition to this kinematic identification of the elastic process provided by the measurements of the forward going momenta, we will use a recoil particle side-arm, similar to that to be used for Experiment No. 96, to make coincidences with the forward going proton and the recoiling pion in order to discriminate the elastic processes from the inelastic u-channel processes.

The process $\pi^+ p \rightarrow p\pi^+$ is considerably more difficult to measure. The input beam electronics will be arranged to identify π^+-mesons via a coincidence with a threshold Cerenkov counter and the Disc counters will be used to veto protons. The rejection of unwanted t-channel events will then be based upon the following criteria.

a) Kinematics: forward going protons from baryon exchange will have momenta ~450 MeV/c (M/2) above the momenta for elastic t-channel processes from either incident protons or pions, and about 700 MeV/c higher than t-channel processes which produce a backward pion in the lab. At 75 GeV the focussing spectrometer should determine momenta to a precision of 25 MeV/c, and thus permit the clean kinematic separation of u-channel from the t-channel processes.

A small fraction of events will result from the t-channel scattering of a proton accompanied by a pion in the input beam. Occasionally the proton will have failed both to have triggered the

Disc counter and its momentum hodoscope counter, and will therefore be misassigned the momentum of the accompanying pion. The maximum possible error in the momentum of these beam particles will be the 1/2% momentum bite of the beam line. Even for this case the real u-channel scatters will be separated by ~ 200 MeV/c from these spurious t-channel processes and will be separated and thus even for the worst possible case these criteria should suffice. Therefore on the basis of kinematics alone we should achieve rejection ratios in excess of 10^4.

b) Input beam particle identification: even at the highest expected beam rates the combination of the threshold Cerenkov pion coincidence, and the Disc proton anti-coincidence should give rejections against protons well in excess of 10^2.

c) Identification of the outgoing particle in the spectrometer: with the threshold and differential counters we would expect to obtain rejection rates well in excess of 10^4:1 against pions going through the high energy spectrometer.

d) Side-arm Kinematics: on the basis of coplanarity and rough azimuthal angle we expect rejection ratios of above 10^2 against unwanted events.

We therefore expect to reject the backgrounds from input beam pions which t-channel scatter into the spectrometer on the basis of forward kinematics, identification of the outgoing fast particle as a proton, and the side-arm kinematics with a combined rejection ratio in excess of 10^{10}. Input beam protons which t-channel scatter into the spectrometer will be rejected on the basis of the forward kinematics, the input beam identification as a "pion", and the side-arm kinematics, with a combined rejection ratio of 10^8.

In addition to this separation into the u-channel, the detected u-channel processes must be analyzed into elastic or non-elastic channels. The same criteria will be used as for $\pi^- p \rightarrow p \pi^-$ namely:

1) The .03% resolution of the focussing spectrometer should be sufficient to kinematically separate the elastic peak from other processes.

2) The residual contamination in the focussing spectrometer comes from the process $\pi p \rightarrow p\ 2\pi$, which is roughly comparable in cross section. This should be rejected (~100 to 1) by the side-arm coincidence. Either criterion 1) or 2) should probably be sufficient.

We believe that the above statements have been well confirmed by previous experimental experience. Using a high precision spectrometer at the SLAC, even with a bremsstrahlung beam and no recoil coincidence, u-channel "elastic" channels have been measured at SLAC up to 16 GeV with a very clean signal(2). With the exception of the BNL experiments of E. W. Anderson et al.(3), u-channel measurements at proton accelerators have not employed forward going spectrometers of sufficient precision to give a clean kinematic separation of the t from the u-channel and have not had sufficient precision to separate the u-channel elastic and inelastic processes. Most previous proton accelerators' experiments(4) have had to rely on very elaborate side-arm detectors to provide clean experimental signatures. The BNL experiments of Anderson, et al.(3) used a 0.25% precision single arm spectrometer and made clean u-channel measurements up to energies of 16 GeV.

Rates and Cross-sections

We give estimates of the expected cross-sections in Table 1, and expected rates in Table 2. Fig. 1a and 1b give the current NAL estimates for the beam intensities of the 2.5mr beam.

Time Required

We are proposing to measure π^+, π^-, K^+, K^-, p and $\bar{p}$ elastic and quasi-elastic large t-value scattering on liquid hydrogen at 50 GeV, 100 GeV, and 150 GeV.

We propose to measure u-channel $\pi^- p \rightarrow p \pi^-$ and $\pi^+ p \rightarrow p \pi^+$ in the range of u-values from 0 to $1(\mathrm{GeV}/c)^2$ at 40 and 75 GeV incident energy on liquid hydrogen. t-channel measurements will proceed simultaneously on all input beam particles. Time estimates follow.

t-channels

π^+, K^+, p channel at 50, 100, 150 GeV to cover 7 decades in $d\sigma/dt$ for the π^+, 6 for the K^+, and 8 decades for the proton.	250 hours
π^-, K^-, $\bar{p}$ channels at 50, 100, 105 GeV to cover 7 decades in $d\sigma/dt$ for the π^-, 5 for the K^-, 2 decades at the higher energies to 5 at the lower energies for $\bar{p}$.	250 hours

u-channels*

$\pi^+ p \rightarrow p \pi^+$ at 40 and 75 GeV to cover 1.5 decades	150 hours
$\pi^- p \rightarrow p \pi^-$ at 40 and 75 GeV to cover 1.5 decades	150 hours
TOTAL	800 hours

* We assume for these measurements secondary pion fluxes in a 1/2% momentum band in excess of 2 10^7 π/per pulse. If actual intensities are lower these measurements will become marginal.

Apparatus Requirements

The 2.5mr beam and the SASG spectrometer facility. No additional special requirements.

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(3) E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick, J. Menes, and F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon, J. Mucci, and J. Russ, Phys. Rev. Letters 20, 1529 (1968).

(4) J. Orear, R. Rubinstein, D. Scarl, D. H. White, A. Kirsch, W. Frisken, A. Read, and H. Ruderman, Phys. Rev. 152, 1162 (1966). H. Brody, R. Lanza, R. Marshall, J. Niederer, W. Selove, M. Shochet, and R. Van Berg, Phys. Rev. Letters 16, 828 (1966). A. Ashmore, C. Damerell, W. Frisken, R. Rubinstein, J. Orear, D. Owen, F. Peterson, A. Read, D. Ryan, and D. White, Phys. Rev. Letters 19, 460 (1967). D. P. Owen, F. C. Peterson, J. Orear, A. L. Read, D. G. Ryan, D. H. White, A. Ashmore, C.J.S. Damerell, W. R. Frisken, and R. Rubinstein, Phys. Rev. 181, 1794 (1969).

TABLE 1

Elastic Cross-sections

Expected cross-sections for the t-channel are given in terms of $d\sigma/dt = Ae^{Bt}$

Process	σ_{tot} (mb)	A (mb/GeV^2)	B (GeV^{-2})	$\sigma_{Elastic}$ (mb)	Comment
$p + p$	40	80	8	10	Falling slowly
$\pi + p$	25	32	9	3.5	Constant
$K + p$	22	25	8	3.1	Constant
$\bar{p} + p$	52	135	9	14	Falling slowly

Expected cross-sections in the u-channel can be approximately represented by

$$\left(\frac{d\sigma}{du}\right)_{u=0} = \frac{300}{E^2} \quad \mu b/\mathrm{GeV}^2$$

TABLE 2

Expected Rates at 60 GeV

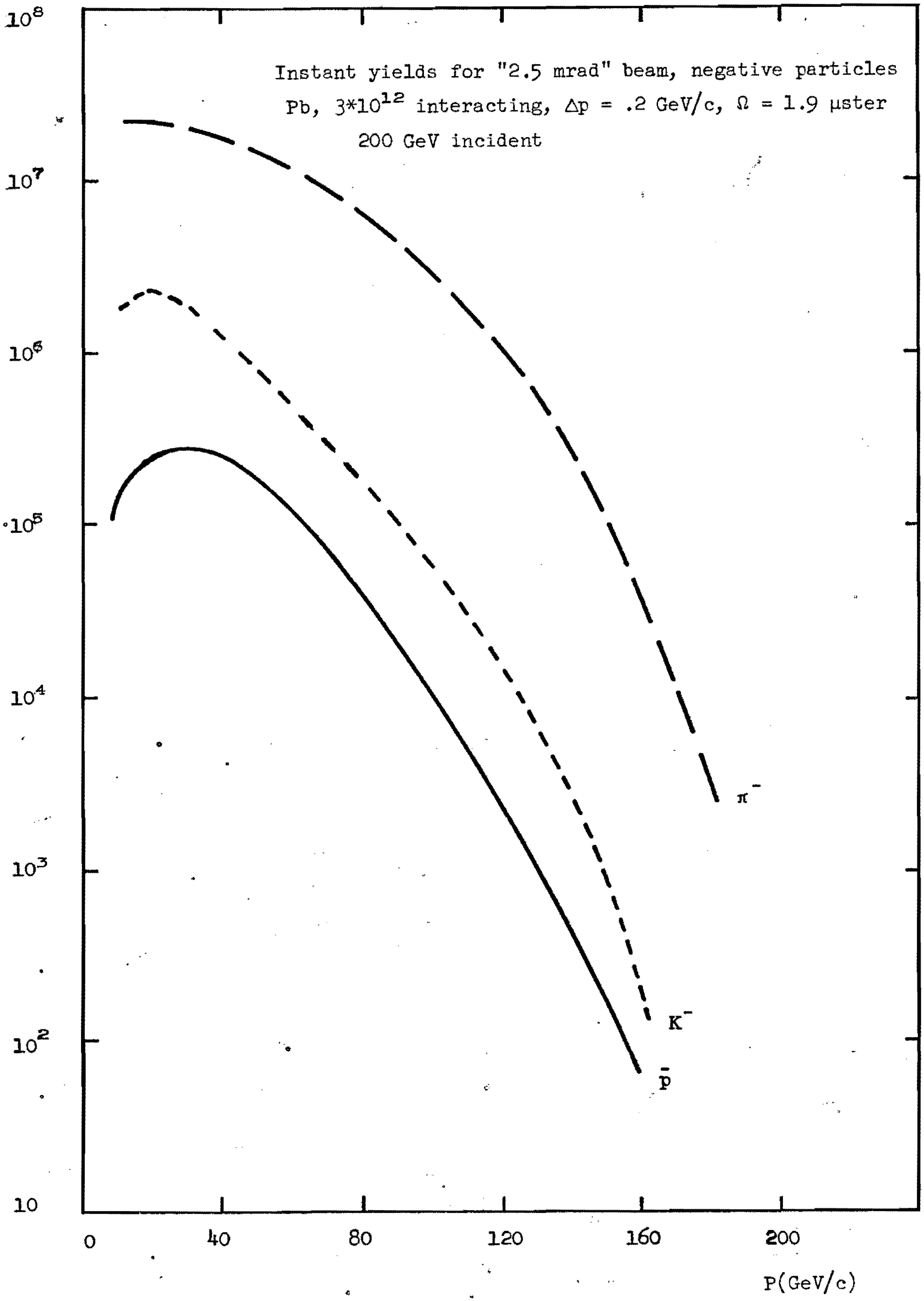
We assumed a solid angle acceptance of the high energy spectrometer of 20 microsteradians, a 20" liquid hydrogen target, and $3\ 10^{12}$ protons per accelerator pulse at 200 GeV.

Process	Beam Intensity per burst	"counts/hours" at small t or u	No. of decades in $d\sigma/dt$ over which cross-section can be measured
t-channel			
pp	$2\ 10^7$	$4\ 10^9$	8
$\pi^\pm p$	$2\ 10^7$	$2\ 10^8$	7
K^+p	$2\ 10^6$	$2\ 10^7$	6
K^-p	$5\ 10^5$	$5\ 10^6$	5.5
$\bar{p}p$	10^5	$2\ 10^6$	5
u-channel			
π^-p	$2\ 10^7$	100	1.0
π^+p	$2\ 10^7$	100	1.0

Expected Rates at 150 GeV

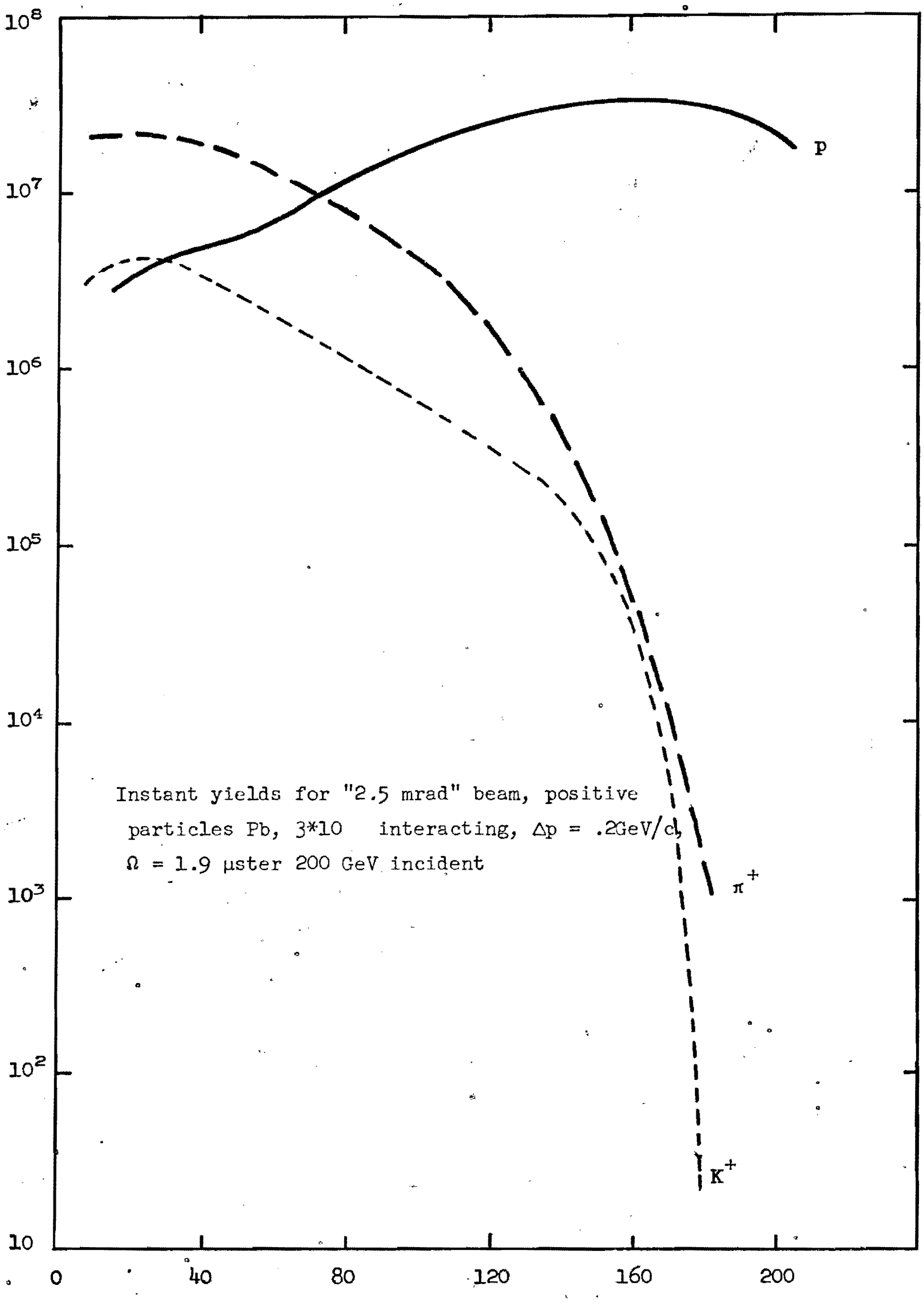
Assumed solid angle acceptance of the high energy spectrometer, 10 microsteradians.

pp	$5\ 10^7$	$2\ 10^9$	8
$\pi^\pm p$	$.2\ 10^5$	$.4\ 10^6$	6
K^+p	10^5	$1.5\ 10^6$	5
K^-p	10^3	$1.5\ 10^4$	4
$\bar{p}p$	10^2	$1.5\ 10^3$	2



10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
0
40
80
120
160
200
P(GeV/c)
Instant yields for "2.5 mrad" beam, negative particles
Pb, $3*10^{12}$ interacting, Δp = .2 GeV/c, Ω = 1.9 μster
200 GeV incident
π^-
K^-
$\bar{p}$

FIG. 1a



Instant yields for "2.5 mrad" beam, positive particles Pb, 3*10 interacting, Δp = .2GeV/c, Ω = 1.9 μster 200 GeV incident

FIG. 1b

ADDENDUM TO PROPOSAL 165

9/18/74

by

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Proposal 165 was written in December 1971. We are now updating it to bring it into line with current operating experience and with present physics interests.

We also propose to combine with the authors of Proposal 99 to measure the exchange process $\pi^+ + P \rightarrow K^+ + \Lambda^+$ with the SAS.

In view of the success of Regge trajectories in describing $\pi^-\pi^0$ charge exchange scattering, it is clearly desirable to see how well this success extends to a wider range of processes.

The successful performance of the Cerenkov systems incorporated in the SAS makes this a comparatively easy experiment to perform. One must ensure that the incoming π^+ in the incident beam is unaccompanied by a K-meson, and that the outgoing particle is a K-meson. The present spectrometer setup has heavy overkill for this type of particle discrimination. We believe that the old Proposal 99 is essentially correct and that the experiment would require one six-week cycle of the accelerator. We are submitting a separate addendum with the authors of Proposal 99, and would propose to run this experiment prior to the Experiment 165 running. Estimating the time required to clean up our present experiment and to incorporate modifications to the equipment, we would expect to be ready to run in Fall '75.

Proposal 165 was considered in large part as a "followup" on Experiment 96, the present ongoing experiment to measure elastic and quasi-elastic scattering with the SAS. We would propose at a time subsequent to the π^+ exchange measurements to take advantage of the increasing targeting fluxes that are now becoming available and would operate the spectrometer in the "energy loss" mode where no information is required from the beam line other than the incident particle types. We would devote our major effort to obtaining improved $\frac{d\sigma}{dt\,dMM^2}$ measurements for $K^\pm$'s and $\bar{p}$'s and fine detail for pions out to MM^2 of $\sim 30\ \mathrm{GeV}^2$ and over a $|t|$ range of $0.02 - 0.4\ (\mathrm{GeV}/c)^2$. Pion measurements should already be covered by Experiment 96 and results for K's and $\bar{p}$'s should also have been obtained. However, for instance, our spring running was restricted to 1×10^{12} protons/pulse by targeting problems and fluxes at least a factor five higher should be available. Furthermore, it was decided for our present experiment that switching back and forth from one mode of operation, i.e., the tagged beam mode to an energy loss mode, would lose as much time as it gained, as beam tagging is required for many of our present objectives.

The spectrometer and beam line instrumentation have excellent particle identification through threshold and differential Cerenkov counters. Backgrounds from particles of wrong momenta interacting in the spectrometer walls and sending secondaries through the detectors are less than 1 in 10^{-3}.

We would propose to parametrize our data in the form:

$$\frac{d\sigma}{dt\, dMM^2} = \frac{A_1 f_1(t)}{MM^2} + \frac{B f_2(t)}{S}$$

The first term corresponds to the triple pomeron (PPP) contribution and the second term to the (PPM) contribution. Probably most significant is the small $|t|$ dependence of the triple-pomeron term, which is expected to flatten or turn over at $|t|$'s of 0.1 $(GeV/c)^2$. Fig. 1 gives the rates for a typical MM^2 interval versus $|t|$ for K^+'s, K's, p's, at 100 GeV that will be observed.

Table 1 gives estimated times for running various t-sweeps and energies. The total estimated time is 475 hours. No significant additional instrumentation would be required.

u-channel processes, both elastic and inelastic, are currently of high interest, both generally and in the context of Regge theory. Even a limited range of measurements at small u-values would be of interest. $\pi^- p \rightarrow p + \pi^-$ is easy to instrument for. The beam line is set for negative particles and the spectrometer is set to detect positive protons at the kinematic limit for recoiling protons. There is every reason to expect that this will be a background free regime (although this has not been checked). $\pi^+ + p \rightarrow p + \pi^+$ has substantial background possibilities from the competing elastic forward scattering of $p + p \rightarrow p + p$. Certainly for π^+ u-channel scattering, the additional constraint provided by the recoiling particle is required. Whether the present recoil arm would be sufficient, or whether additional rough information on the recoiling momenta would also be needed, is not clear. Typical rates for targeting at with $5 \cdot 10^{12}$ protons /pulse, using a 30" L. H. target and taking $\frac{d\sigma}{du}$ to be 10^{-32} cm^2 (the "predicted" cross section at u = 0) would give ~ 10^3 counts/4 days at 50% efficiency for elastic π^+ scattering, and ~ 330 counts/4 days at 50% efficiency for π^- scattering. Two or three times more quasi-elastic events of definite physics interest would also probably be observed. Various forms of upgrading the spectrometer, such as the use of 4" quads instead of the present quads, would substantially improve these numbers. Therefore, this experiment appears relatively attractive. If, however, the cross sections were substantially lower than estimated, this experiment would become unattractive. We would therefore request an early two-day checkout run using π^- mesons to obtain a rough cross-section value while the apparatus is set up for Experiment 96. On the basis of this, we would be able to make a firm proposal for this part of the program.

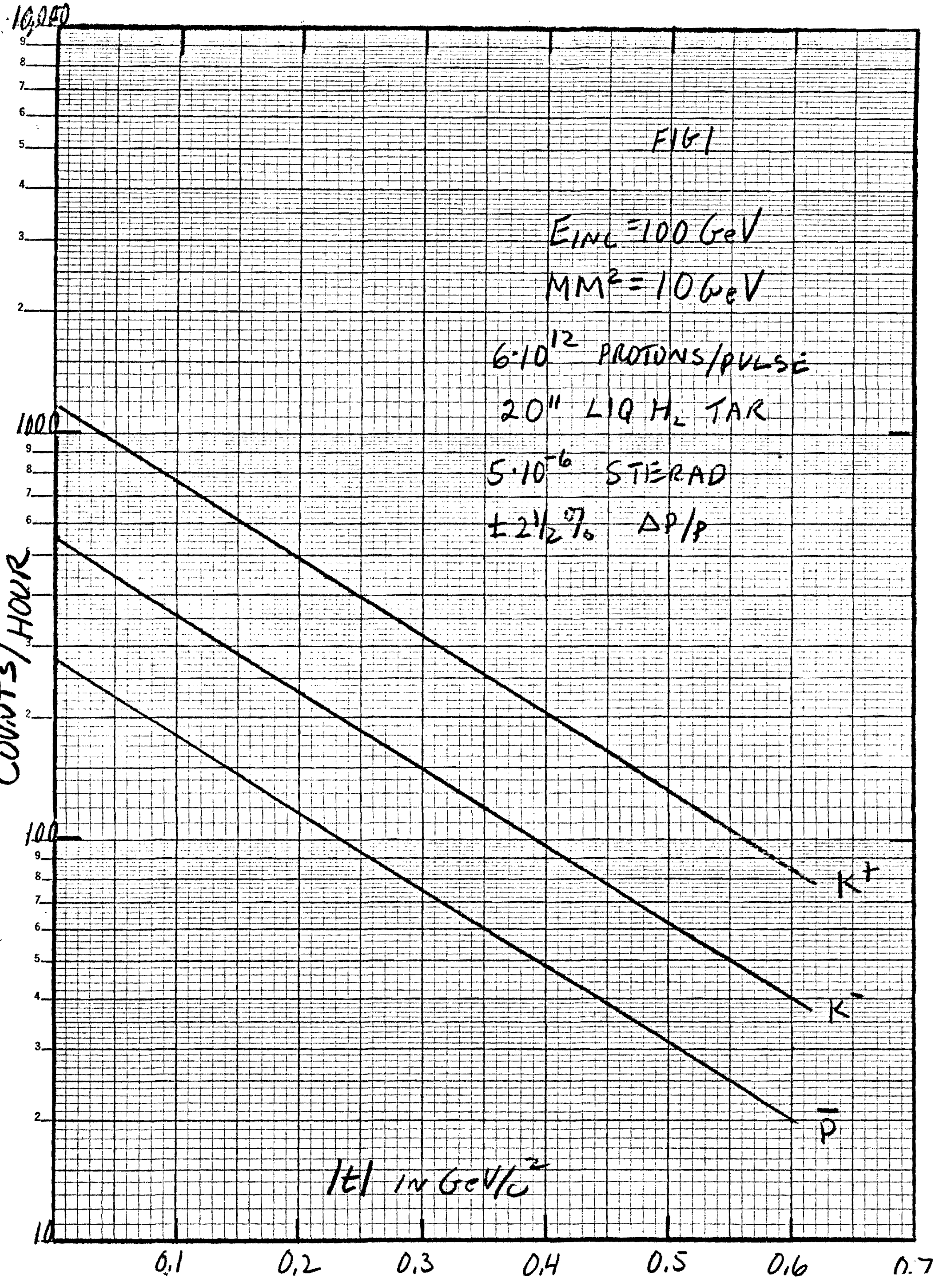
TABLE 1

Proposed time estimates for $d\sigma/dtdMM^2$ for $K^\pm$ and $\bar{p}$. Assuming a 20" liquid H_2 target, 6×10^{12} protons / pulse, $\Delta p/p$ acceptance ± 2 1/2%, 10 μster at 50 GeV/c and 5 μster for $\geq$ 100 GeV/c and 10% precession.

ENERGY	$\|t\|$ RANGE	$\|t\|$ STEPS	MM^2 RANGE	MM^2 STEPS	TIME
±50 GeV	.02 - 0.45	3	0 - 30 GeV^2	5	150 hours
±100	.02 - 0.45	5	0 - 30 GeV	5	100
±175	.02 - 0.45	2	0 - 30 GeV	4	150

SET UP AND OVERHEAD	75
TOTAL	475 HOURS

FIG 1



$E_{INC} = 100$ GeV

$MM^2 = 10$ GeV

$6 \cdot 10^{12}$ PROTONS/PULSE

20" LIQ H_2 TAR

$5 \cdot 10^{-6}$ STERAD

±2½% $\Delta P/P$